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Considerations in the Selection of a Growing Medium for the Aerial Dart Seeding System

J. B. Scarratt

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CONSIDERATIONS IN THE SELECTION OF A GROWING MEDIUM FOR THE AERIAL DART SEEDING SYSTEM

J.B. SCARRATT

GREAT LAKES FOREST RESEARCH CENTRE

CANADIAN FORESTRY SERVICE

DEPARTMENT OF THE ENVIRONMENT

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ABSTRACT

An aerial dart seeding system has been developed that appears to offer greater control over seed distribution and subsequent seedling spacing than conventional direct seeding techniques. This report discusses some of the constraints that must be taken into consideration in selection of a growing medium for use with aerial darts and presents results of a preliminary test to compare the drying rates of various commercial growing media. It is concluded that soilless growing media intended for horticultural use are unable to satisfy the stringent moisture requirements for satisfactory performance of aerial darts. While some improvement in moisture characteristics may be possible through manipulation of the physical condition of such media, the use of hydrophilic polymer additives appears to hold the greatest promise for substantially increasing the moisture retention of soilless media.

RÉSUMÉ

Une nouvelle méthode d'ensemencement par aéronef de graines emballées sous forme de dards semble permettre de mieux gouverner la distribution des graines et l'espacement futur des semis que les techniques classiques d'ensemencement direct. Quelques-uns des facteurs à considérer dans le choix du milieu de culture à employer dans les dards sont examinés dans ce rapport, ainsi que les résultats d'un essai préliminaire visant à comparer les vitesses d'assèchement de divers milieux de culture du commerce. L'auteur conclut que les milieux de culture sans sol employés en horticulture ne peuvent satisfaire aux exigences strictes d'humidité pour assurer un rendement satisfaisant des dards. Si une certaine amélioration des caractéristiques d'humidité par manipulation des conditions physiques de ces milieux reste possible, l'addition de polymères hydrophiles semble la façon la plus prometteuse d'accroître substantiellement la rétention de l'humidité dans les milieux sans sol.

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Note: The mention of trade names or products in this publication does not imply that they are specifically endorsed or recommended by the author or the Great Lakes Forest Research Centre in preference to similar products not mentioned.

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INTRODUCTION

An aerial dart concept for direct sowing of coniferous tree seeds was first proposed by the Canadian Forestry Service's Forest Management Institute in the mid-1970s. In 1976 the National Aeronautical Establishment of the National Research Council undertook to investigate the feasibility of developing such a system. Since that time considerable technical progress has been made in designing the aerial dart and in developing an aerial delivery system (Fig. 1) based upon use of a light helicopter equipped with a highly accurate, short-range, electronic navigational system (Wood 1981, 1984).

Figure 1. Light helicopter fitted with two prototype dispensers for dropping aerial darts sequentially (second dispenser mounted on other side of aircraft).

Proponents of the aerial dart system have suggested that the concept, in contrast to conventional aerial seeding methods that use naked or pelletized seed, offers three important potential advantages (Wood 1981), viz:

i. more reliable seedling establishment (Seeds, together with a small quantity of growing medium, are packaged in small darts which, on release from the aircraft, penetrate the ground. The dart would provide a more favorable micro-environment for germination and early seedling growth and, as a result of ground penetration, developing seedling roots would have early access to the surrounding mineral soil.);

ii. reduced need for seedbed preparation on certain sites (e.g., recently burned or freshly harvested), in consequence of the dart's being able to penetrate surface materials that might otherwise interfere with germination and early growth;

iii. greater control over seedling distribution and "sowing" density by virtue of the aerial dispensing and delivery system.

Substantial progress has been made in perfecting the aerial dart and associated delivery system, to the point at which reasonably good ground distribution of darts can be achieved along the line of flight (Wood 1981, 1984). There is a capability for adjusting average linear spacings within the area of impact, although it is obviously not possible to target specific microsite locations. The latter has implications, with respect to depth of dart penetration at point of impact, that obviously go beyond concerns over straight delivery. Because the typical forest cutover presents a mosaic of microsite conditions, each differing in its resistance to penetration, there is likely to be considerable variation in depth of dart penetration on most sites. Whether this will be acceptable, or can be easily moderated, remains to be determined. From a biological viewpoint the optimal range of penetration would appear to be rather narrow.

Notwithstanding development of a successful delivery system, the results of field trials have been rather disappointing. Both in actual and in simulated aerial drop situations on cutover sites, seedling establishment rates were generally low. Supplementary trials showed that, even where germination was reasonably good, progressive depletion of seedling numbers over the course of the summer inevitably led to a high failure rate. By far the highest proportion of losses appeared to occur at the pregerminant or germinant stages of seedling development, a fact that points to especially critical environmental conditions within the growing medium.

Although such factors as inadequate dart penetration and unsuitable microsite "hits" undoubtedly contributed to the poor results observed in the field trials, desiccation of the growing medium within the dart was the principal cause of establishment failure. This strikes at the heart of the aerial dart concept, which is founded on the premise that seeds are delivered to the site in a protective package that favors germination and early seedling growth. Clearly, if the aerial dart is to have any chance of operational success, it is crucial that attention be given to the selection or development of a growing medium whose composition and physical properties, particularly with regard to moisture absorption and retention, will reliably support germination and early growth under typical site and weather conditions in northern Ontario. This report discusses some of the constraints that must be taken into consideration

in selection of a growing medium for use with aerial darts, and describes results of a preliminary drying test with commercial horticultural media.

AERIAL DART DESIGN

The aerial dart comprises a biodegradable container with a plastic nose cone to aid soil penetration (Fig. 2 and 3). The container section is a truncated paper cone with fold lines that form three fins when the dart is closed and sealed. This paper cone is clamped into the nose cap by means of a matching ballast plug to form the dart assembly. Both the injection-molded nose cap and the ballast plug are manufactured from a heavily filled ($BaSO_4$) plastic. This provides the weight necessary to ensure aerodynamic stability and adequate soil penetration on impact with the ground.

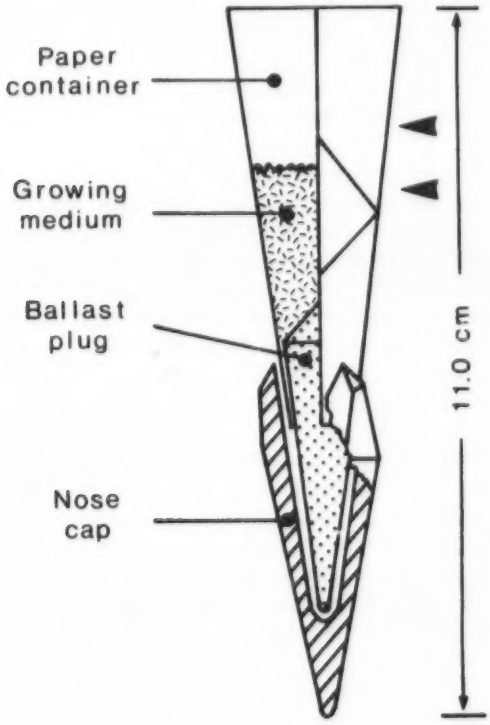

Figure 2. Cross section of aerial dart (horizontal arrows indicate preferred "sowing" depth range).

When closed, the dart has a growing medium capacity of 10 ml. The folded fins of the paper container (Fig. 4) are sealed with a water-soluble glue that is quickly dissolved by the first rain after "sowing", allowing the fins to unfold and the container to open (Fig. 5 and 6). A light shower should be sufficient to release the seal, although the dart may open without rain in soils

with a high moisture content. Average weight of the dart as used in the air-drop trials was 15 g empty and 20 g filled; the large difference was mostly a result of adding silica sand to the growing medium in order to achieve the desired gross weight (see footnote, page 5). However, since the silica sand undoubtedly contributes to rapid desiccation of the growing medium, it seems that such ballasting could be avoided, without changing gross dart weight, simply by adjusting the specific gravity of the nose cone.

Although the dart is intended primarily as a vehicle for dispensing seeds and supporting them during the critical germination and seedling establishment phases, its design characteristics are dictated largely by the requirements of the aerial delivery system. Consequently, the essential criteria of aerodynamic stability, low drag and the ability to penetrate the ground surface have been key factors determining the design, weight and volume of the aerial dart. While both mechanical and biological compromises have obviously been necessary in reaching the present configuration, there can be little doubt that the very small volume of growing medium carried by the dart imposes a major biological constraint upon the system.

GROWING MEDIUM SELECTION

Moisture availability and temperature conditions in the seedbed are principal factors determining early success in direct seeding operations. However, while low soil temperatures in spring may initially retard germination of coniferous seeds, and high surface temperatures may later kill young seedlings, in practice, on boreal sites in continental Canada, we are usually most concerned with avoiding moisture deficits in the seedbed. Whether we are dealing with conventional direct seeding onto scarified cutover sites or with aerial darts containing their own growing medium, the moisture retention capacity of the "seedbed" is critical for germination and the survival of young seedlings.

The period over which the growing medium in an aerial dart is called upon to support germination and seedling growth will normally be rather short. Once germination has started, a seedling will remain dependent upon the dart for perhaps no more than a month to six weeks under favorable temperature and moisture conditions. However, it is the ability of the growing medium to support germination and early seedling development under adverse moisture conditions that inevitably will mean the difference between success and failure.

Borrowing from Baker (1950), we may recognize four distinct stages in the establishment of a seedling from an aerial dart:

i. the germination stage, which begins with imbibition of water by the seed and ends when the germinant first appears above the seedbed surface;

ii. the succulent stage, which ends with hardening of the seedling hypocotyl;

iii. the juvenile dependent stage, which lasts until the young seedling becomes independent of the growing medium in the dart;

iv. the juvenile independent stage, which lasts for an indefinite period until the seedling has become well established.

The first two stages are undoubtedly the most critical in relation to moisture supply. Once germination starts, both germinant and young seedling are highly susceptible to desiccation, and a constant source of moisture is essential for their continued survival and development. Even short periods of surface desiccation may be fatal during this period. Furthermore, while Place (1955) considered that most seedlings die from drought on hot seedbeds because of excessive transpiration stress and rapid desiccation of the seedbed, there is ample evidence to indicate that seedlings in the succulent stage are also very susceptible to direct heat injury (Arnott 1974).

Susceptibility to desiccation is likely to diminish as the seedling hardens and its root system proliferates into the surrounding natural soil. Although the roots of the developing seedling are initially confined to the growing medium within the dart, and are therefore dependent upon it for moisture, the evidence indicates that rapid disintegration of the paper cone in moist soils quickly eliminates any potential barrier to root egress. Once roots start to grow into the surrounding soil the seedling quickly becomes independent of the growing medium in the dart and subject to the normal hazards of the site. It may be noted that the configuration of the dart's nose cone has not been observed to affect seedling root form adversely in established seedlings.

In the field trials carried out prior to 1983 the growing medium was essentially a mixture of shredded peat moss and silica sand.[1] Thus, in the 1982 trials the darts were filled with a mixture of four parts by volume of Metro-Mix® 200 and one part #40 silica sand, capped with a vermiculite seed cover. While controlled plantings of darts filled with this growing medium have shown that vigorous seedlings can be grown under optimal moisture conditions, it is evident that the moisture reserve is inadequate to support germination and early growth under less favorable site and weather conditions. The susceptiblity of such media to rapid desiccation, exacerbated by the small capacity of the dart, means that even a short period of drying may lead to heavy seedling losses, especially if it coincides with the critical period of radicle emergence and early root establishment.

Selection of a more suitable, water-retentive growing medium is clearly essential if the aerial dart is to have any chance of biological success under typical application conditions. A number of factors need to be borne in mind during medium selection, *viz:*

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[1] Silica sand was added principally to adjust gross dart weight to that required to achieve the correct impact velocity. However, the need for such ballasting could be offset by increasing the amount of filler in the plastic nose cone. This would have the added advantage of lowering the centre of gravity in the dart, and would, it is presumed, improve the dart's aerodynamic stability.

- The dart was designed for use principally with jack pine *(Pinus banksiana* Lamb.) and black spruce *(Picea mariana* [Mill.] B.S.P.), two species that germinate quickly and uniformly under favorable temperature and moisture conditions. Neither species requires seed stratification. Once germination has begun, radicle development and root penetration into a soil substrate are fairly rapid in jack pine; however, root development in black spruce is much slower, and more likely to be overtaken by surface desiccation of the growing medium during dry spells.

- The literature on direct seeding provides no conclusive evidence to recommend either fall or spring sowing one over the other *(vide* Cayford 1974). Each season has its advocates, although the majority of authors appear to prefer spring sowing of spruce and pine (Arnott 1974). In practice, the choice often depends on which time of year is operationally the most convenient for carrying out the work. This may explain why a large proportion of direct seeding operations takes place in fall, when the pressures of planting and other work are at a minimum. However, it must be remembered that fall sowing increases the length of time seeds are exposed to destructive agents before germination can take place in spring. While this may not be an especially important consideration in terms of the large quantities of seed applied in most broadcast seeding operations, the relative effect, in aerial darts, of overwinter seed losses to rodents, etc., may be far more serious because of the low "sowing" rates involved. (Wood [1981] uses an example of 2545 darts/ha; at 3-5 seeds per dart this is equivalent to only 7,600-12,700 seeds/ha.) An additional concern with fall "sowing" is the possibility that severe frost-heaving of darts might be experienced on exposed mineral soils, as has happened with late plantings of containerized tree seedlings.

- Until the effectiveness of fall "sowing" has been evaluated, it is probable that the aerial dart will continue to be viewed principally as a vehicle for spring "sowing". Certainly, moisture conditions in the seedbed should be close to the optimum at that time. Provided that the risk of frost-heave has passed, the earlier in spring that "sowing" takes place the better in order to take advantage of favorable soil moisture conditions. This will facilitate imbibition of water by seeds and, as soil temperatures increase, should allow germination to begin before the onset of the typical drought period in late spring. Even so, the spring germination window may be rather narrow.[2] In northern Ontario, dry spells can occur as early as mid-May, and coarse-textured soils especially may dry out rapidly. Growing medium selection should clearly be based upon such an eventuality.

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[2] Nursery experience is relevant here: at the Swastika nursery (Kirkland Lake) fall sown spruce and pine seeds generally do not germinate until late May, despite the fact that irrigation of the seedbeds (loamy sand) usually must be started in the first week of May to avoid drying of the soil surface (L.J. Forcier, Ontario Ministry of Natural Resources - personal communication).

- To avoid premature germination, or loss of germinative vigor of seeds through incomplete imbibition, the moisture content of the growing medium should not exceed 10% during pre-drop storage and handling. However, because dry peats are frequently hydrophobic, this requirement may create difficulties in the rewetting of peat-based growing media after the darts are "sown" in the forest. For this reason it may be necessary to incorporate a wetting agent into the medium to aid rapid moisture absorption during periods of rainfall. (An alternative might be to fill the darts with moist growing medium and store them frozen to avoid premature germination. However, this approach might create additional logistic problems and would certainly reduce system flexibility. Furthermore the darts would have to remain frozen until dropped to avoid seal breakdown. This would create the need for special refrigeration facilities at the aircraft landing site.)

- Moisture is required to break the dart seal and to initiate germination. It is questionable whether moisture absorption from the surrounding soil can be relied upon to wet the growing medium sufficiently to support germination in spring-sown darts. Under most circumstances, rainfall will probably be the principal source of moisture. With organic growing media especially, both the amount and distribution of rainfall will obviously be important in determining the success of germination and seedling survival. Once the growing medium starts to wet up, it must be able to absorb and store sufficient moisture to promote rapid germination and enable the germinant radicle to become firmly established. It cannot be assumed that the first rainfall after "sowing" will be sufficient to saturate the growing medium, so that it may be desirable to include additives, such as hydrophilic polymers, which are able to absorb large quantities of water, releasing it to the seed or seedling on demand. In this manner it may be possible both to accumulate moisture from light showers and, once the growing medium is fully wetted, to prolong moisture availability during subsequent periods of dry weather.

- Physical stability of the growing medium during wetting and drying cycles is important to avoid a) possible loss of hydraulic conductivity between the contents of the dart and the surrounding soil, and b) possible damage to the roots of young seedlings, as might occur if the growing medium were susceptible to shrinkage upon drying.

Soilless Growing Media

The critical need for high moisture retention, coupled with the small capacity of the aerial dart, makes selection of an appropriate growing medium especially difficult. Our observations indicate that traditional soilless media are unable to satisfy the special moisture requirements of aerial darts. However, except for the possibility that purely artificial substrates with the desired characteristics might come to light, there are few practicable alternatives available. Consequently, the best opportunity for development of a suitable growing medium probably lies in the amendment of existing formulations.

With soilless growing media now widely used both in horticulture and in containerized tree seedling culture, large numbers of ready-mixed products have come onto the market in recent years. For the most part, these growing media are variations on the basic Cornell peat-lite mixtures (Boodley and Sheldrake 1982), with *Sphagnum* peat moss and horticultural grade vermiculite as their principal components. However, increasing numbers of mixes are being marketed in which the peat component is partially or wholly replaced by composted pine or hardwood bark and/or sawdust (Gartner 1981, Blom 1983). The non-organic component may also be varied through use of a wide range of alternative materials, frequently inert, such as perlite, styrofoam beads and other foamed plastics, sintered clays (Turface®) and shales (Haydite®), pumice chips, etc. Choice of materials allows modification of the water-holding capacity, air space, buffering capacity, and bulk density of a growing medium. The composition of some of the principal commercial mixtures available in Canada is summarized in Appendix I; many other mixtures are described in the literature. Most commercial mixtures are supplemented by the addition of wetting agents, ground limestone, and nutrients for specific crop applications. Some manufacturers offer custom-blending of ingredients.

The water holding capacity (WHC) and other physical properties of a growing medium, such as pore space and bulk density, are determined both by the nature of the individual ingredients and by the proportions of such ingredients. The origin, particle size distribution and degree of decomposition of the organic component are especially important in relation to the moisture characteristics of a growing medium. In the case of peats, origin includes both mode of formation and botanical origin of the plant remains (Hammond 1975, Puustjärvi and Robertson 1975), factors which influence the chemical as well as the physical properties of a peat. For horticultural uses as well as for tree seedling production, relatively undecomposed, fibrous *Sphagnum* peats are generally preferred (Hellum 1978), these being characterized by low bulk density, large pore volume, and high WHC. Highly decomposed or humified peats with a high proportion of fines, such as those derived from *Hypnum* and other mosses or from sedges/grasses, are considered unsuitable for horticultural use. Of course, these restrictions apply for the most part to seedlings grown in a greenhouse environment; conditions are very different in aerial darts, and may dictate other criteria for selection of a peat component.

While a reduction in particle size is a natural accompaniment to the decomposition of plant residues in peat, it is supplemented by the mechanical degradation that occurs during harvesting and processing. In fibrous peats the amount of mechanical damage incurred, and hence particle size distribution, is closely related to the method of harvesting. Consequently, block-cut and hydraulically mined peats are usually coarser, with less fibre damage, than the more common milled, vacuum-harvested peats.

The WHC of *Sphagnum* peat moss is substantially greater than that of composted bark. For this reason, a peat-based material would appear initially to offer the best starting point for developing a suitable growing medium. However, the ability to retain available water for plant growth at high moisture tensions, an essential requirement for aerial darts, is not necessarily propor-

tional to the WHC of a material (Beardsell et al. 1979). Thus, the high WHC of undecomposed *Sphagnum* peat is offset by a very high rate of water loss through evaporation and easy exploitation by the plant. Because of the large pore volumes in such peats, most of the available water is held at low capillary tensions, and is therefore easily removed. This means that although peat moss can hold large amounts of water, it cannot prevent plants from wilting for very long. Pine bark, on the other hand, because it resists water loss through evaporation, and because its available water is less readily accessible to the plant at low tensions, has been shown to maintain plants in an unwilted state for a longer time than peat moss despite its lower WHC (ibid.). This is not to recommend one material over the other at this point, but rather to point out the need for caution in selecting ingredients for a growing medium. Considerably more information is needed on the moisture relations of different materials under the conditions of intended application, and on the effect of additives, before a growing medium can be developed that will satisfy the moisture requirements for both germination and seedling survival in aerial darts.

Hydrophilic Additives

The use of absorbent additives may offer the most effective means of enhancing the moisture retention properties of soilless media in aerial darts. Several hydrophilic polymers that hold promise for this purpose have come onto the horticultural market in recent years. These are mostly variants of the starch-polyacrylonitrile graft copolymers patented by the United States Department of Agriculture in the mid-1970s (Anon. 1975), products that have found use in a wide range of agricultural and non-agricultural applications. In horticultural use, beneficial results of adding polymers to growing media have been reported in the nursery production of containerized woody ornamentals and bedding plants. These include improved water holding capacity, better water retention, increased time to wilting under moisture stress (reflected in improved market life of bedding plants), and reduced watering frequency (Anon. 1973, Eikhof et al. 1974, Still 1976, Gehring and Lewis 1980, Flannery and Busscher 1982). Increased germination, better plant growth (a result of reduced moisture stress) and improved root development are often claimed in manufacturers' literature as well. In related applications, hydrophilic gels show promise as root dips for improving transplant survival and establishment (Whitmore 1982), and may have value as seed coatings for improving germination (Dexter and Miyamoto 1959, Vartha and Clifford 1973).

Hydrophilic polymers are said to be nonphytotoxic, although Rietveld (1976) reported an unexplained delay and reduction in the germination of Ponderosa pine (*Pinus ponderosa* Laws.) seed on loamy seedspots amended with Hydrogel®. Still (1976), referring to a hardwood bark/sand mixture, has suggested that large amounts of polymer may contribute to poor plant growth by reducing pore space and aeration in the growing medium.

A number of the hydrophilic polymers being marketed for horticultural use (Appendix II) are claimed to be capable of absorbing several hundred times their own weight of water. However, this usually refers to distilled or deionized water while, in practice, absorbencies depend very much on the salt content of

the soil solution[3]. Perhaps of greater significance than the total amount of water absorbed is the fact that most of this water is said to be held at tensions of only -0.1 to -2.0 atmospheres (Anon. 1973, King et al. 1973), so that it is readily available for reabsorption by plant roots. Terra-Sorb®, for example, is said to absorb ten times as much water as peat moss, 95% of which is claimed to be available to plants in comparison with only 40-50% for peat moss.

Although the literature is rather vague about the stability of hydrophilic polymers in the soil, trade literature for Terra-Sorb® indicates an effective life of between three and twelve months. This product is acknowledged to be biodegradable, and its effective in-soil life is said to depend on soil pH, mineral content, soil microbial activity, and the presence of fertilizers. Similarly, Liqua-Gel® "will remain active in the soil for at least one growing season". On the other hand, two other products (Agrosoke®, Aqua-Terra®), both chemically related to Terra-Sorb®, are claimed to be nondegradable in the soil and able to continue drying and rewetting indefinitely. Long-term stability is not a critical issue for application with aerial darts, of course. In this situation a polymer need remain active for only a few weeks, until such time as seedlings become independent of the growing medium in darts.

Most polymers come in powder or crystalline form. Uniform distribution within the growing medium is important, and at least one product (Aqua-Terra®) blends the active ingredient into an inert extender to facilitate mixing. The high absorption capacity of these materials, and the fact that water absorption begins as soon as they come into contact with moisture, requires that they be mixed into a dry growing medium to avoid premature water uptake and consequent distribution problems (e.g., "gumballs"). Fortuitously, this is compatible with the need to use a dry medium to avoid premature seed germination during pre-drop storage of aerial darts.

The superabsorbency of hydrophilic polymers is obviously not gained without substantial expansion on wetting. Crystals of Terra-Sorb®, for example, are said to swell to 30 times their original volume when wetted. Since a high proportion of water absorbed is claimed to be available to plants (95% in Terra-Sorb® and Aqua-Terra®), to what extent will a growing medium shrink as the polymer gives up its moisture charge? Although volume changes in a growing medium will depend upon the amount of additive used, a propensity for massive fluctuations in volume on wetting and drying would be disadvantageous with aerial darts. For reasons outlined earlier, it seems desirable that the growing medium remain physically stable during its wetting and drying cycles, at least during the early stages of seedling development before the roots are firmly established in the surrounding soil. This is an important question to be addressed in any evaluation of such additives for use with darts. If excessive swelling is found

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[3] Absorbencies quoted in specification bulletin (1975) for SGP® 502S ("Super Slurper"):-

Deionized water	:	800-1000 ml/gm
Minneapolis tap water	:	350- 450 ml/gm
Saline solution 0.5% NaCl	:	90- 110 ml/gm
1.0% NaCl	:	70- 90 ml/gm
1.5% NaCl	:	60- 80 ml/gm

to be a problem, then an alternative approach might be to reduce the amount of additive in the growing medium, and either sow the seeds into a small surface concentration of pure polymer or use polymer-coated seeds. The first option might be the most effective for, once the pure polymer is fully wetted, its high moisture reserve could well serve to enhance germination and early seedling survival during the critical germinant phase. However, the use of polymer seed coatings also warrants investigation.

While the polymers described above appear attractive for improving moisture retention in aerial darts, there is a second group of products that also merits investigation. These are internally cross-linked forms of sodium carboxymethylcellulose (cellulose gum) fibre (e.g. Aqualon®), which are claimed to absorb up to 45 times their own weight of water. Though much less absorbent than the hydrophilic polymers discussed above, they exhibit the desirable characteristic of not undergoing any appreciable expansion on wetting. The fibrous nature of the material might make it difficult to achieve uniform mixing with other fibrous components of a growing medium; however, this problem should not be insurmountable on a commercial scale. No information could be found on the moisture retention characteristics of such materials in relation to plant growth.

Wetting Agents

Although the moisture content of a growing medium should be less than 10% to avoid premature germination, rapid rewetting after the aerial darts are "sown" is essential to take advantage of available sources of moisture. Dry peat fibres are usually hydrophobic and, as with most commercial mixtures, wetting agents may have to be incorporated into custom-blended media to facilitate moisture absorption. Of the many wetting agents available, the nonionic surfactants are of greatest interest in plant culture because of their relatively low toxicity (Schwartz et al. 1958). However, severe toxicities have been encountered even in this group; Burridge and Jorgensen (1971), for example, reported that two common commercial wetting agents caused severe inhibition of germination and root growth in several tree species, including spruce and pine. This points to the need for adequate testing before a wetting agent is used operationally and may, indeed, serve as a reminder that commercial growing media containing surfactants should also be screened for specific inhibitory effects upon species of interest.

It is quite possible that the incorporation of absorbent additives into a growing medium might obviate or reduce the need for wetting agents. In quick tests with Terra-Sorb® mixed into air-dried *Sphagnum* peat moss, the presence of the polymer certainly appeared to aid wetting of the peat fibres when water was added. Although rewetting was less uniform than might have been expected from use of a surfactant, this secondary benefit of hydrophilic additives warrants notice.

Fertilizers

There is probably no benefit to be gained by adding fertilizers to the growing medium used in aerial darts. The seeds will contain all the nutrients

required for germination, and seedling roots will probably have grown into the surrounding soil well before any substantial nutrient demand develops. If fertilizers are to be added, it does not appear that anything more than small amounts of phosphorus would be needed to encourage root growth, and perhaps nitrogen to give the seedlings an initial boost. However, it should be emphasized (see footnote 3, page 10) that the absorbency of hydrophilic polymers may be substantially reduced by salts in the soil solution. This means that the addition of excessive amounts of fertilizer to growing media containing such additives could actually be counter-productive.

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The preceding discussion has outlined some of the principal factors to be considered in selection or development of a growing medium for aerial darts. It is evident that the dart imposes special problems with regard to moisture supply that may be difficult to overcome. Nevertheless, it is equally evident that only through the choice of a medium able to satisfy the moisture needs for germination and seedling survival can the dart hope to achieve biological and operational success.

PRELIMINARY COMPARISON OF COMMERCIAL GROWING MEDIA

From the foregoing discussion it is evident that the moisture properties of soilless growing media are strongly influenced by their composition and physical character. Because commercial growing media vary in composition, we might expect also to see variations in water holding capacity, moisture availability and drying rates.

In a preliminary study of moisture retention by soilless media, drying curves were compared for a number of commercial and locally blended mixtures (Appendix III). This test was by no means comprehensive, and was conducted principally to gain some insight into differences in rate of water loss between commercial media and the effects of absorbent additives.

The ten growing media tested showed substantial variation in bulk density and coarseness (Table 1). Only three of the mixtures had bulk densities high enough to have produced filled darts with weights approaching the 20 g necessary to achieve the desired impact velocity (see page 4 and footnote 1, page 5). Of these, one (#5) contained Turface® and another (#8: Metro-Mix® 200) granite sand, both of which served to increase weight. A third medium (#10: Ball Growing Mix I), a mixture based on composted pine bark, was the heaviest of all, yet contained no ballast materials. The pine-bark mixture (#10) and the peat vermiculite mixture with Turface® (#5) also had the lowest water holding capacities. By contrast, the incorporation of granite sand into the Metro-Mix® 200 had no apparent adverse effect upon the water holding capacity of that medium. The low value for the pine bark mixture may be attributable in part to the coarseness of the material, and to the lack of peat moss in this particular product.

Table 1. Physical characteristics of selected soilless growing media.

Growing medium	Bulk density[a] (mg/cm^3)	Fines[b] (%)	WHC[c] (%)
A. Locally blended mixtures			
1. Peat moss (Fafard brand)	196.7	70.4	76.5
2. Peat moss:vermiculite (1:1)[d]	160.6	55.2	83.2
3. Peat moss:vermiculite (1:1) plus Aqua-Terra®			87.1
4. Peat moss:vermiculite (1:1) plus "Super-Slurper"			88.9
5. Peat moss:vermiculite:Turface®	383.4	60.9	66.6
B. Commercial mixtures			
6. Jiffy Mix	181.3	95.0	83.6
7. Redi-Earth®	226.7	91.6	84.7
8. Metro-Mix® 200	352.0	77.3	84.7
9. Forestry Mix	196.4	72.2	85.3
10. Ball Growing Mix I	466.2	57.4	69.8
11. Pro-Mix A	236.3	62.0	79.8
12. Pro-Mix BX	195.7	64.6	81.6

[a] Air-dry weight basis. Sample containers with an approx. vol. of 48 cm^3 filled on a vibration table. (n = 20)

[b] Percentage of constituents passing through a 2-mm mesh sieve. (n = 5)

[c] WHC = Water holding capacity at "field capacity" (as percentage of fresh weight).

[d] Proportions on a volume basis; Fafard brand peat moss was used for all locally blended mixtures.

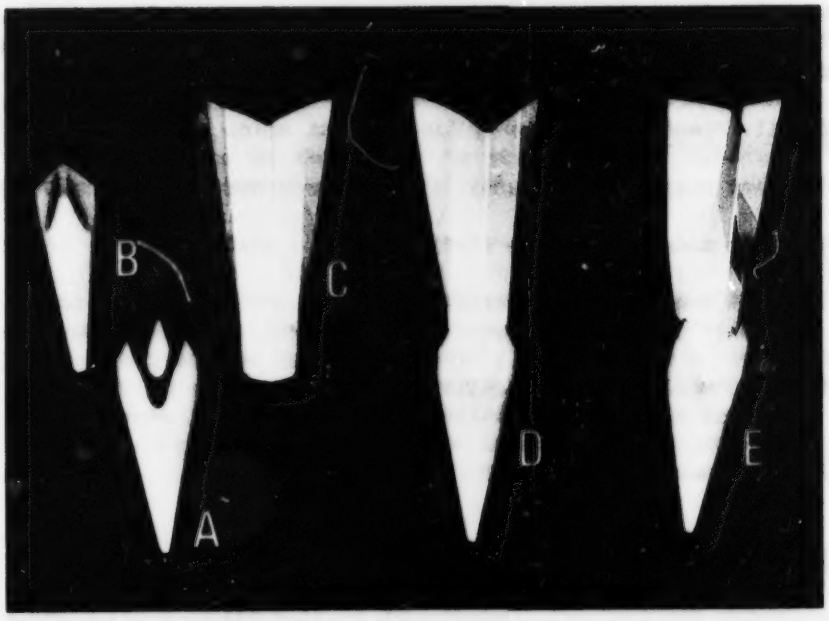

Figure 3. Aerial dart components: A - nose cap; B - ballast plug; C - paper container; D - dart assembled, open; E - dart assembled, fins sealed.

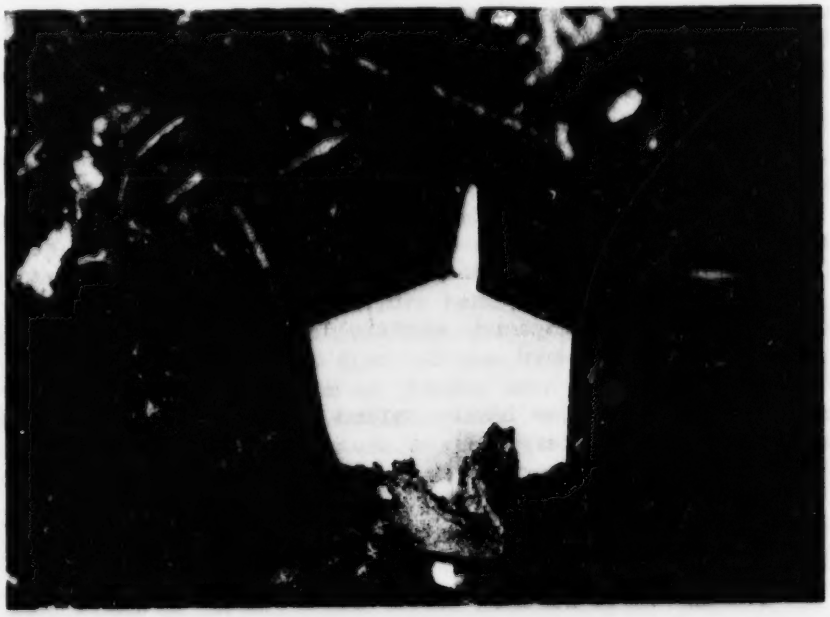

Figure 4. Aerial dart shortly after impact, before breakdown of fin seal.

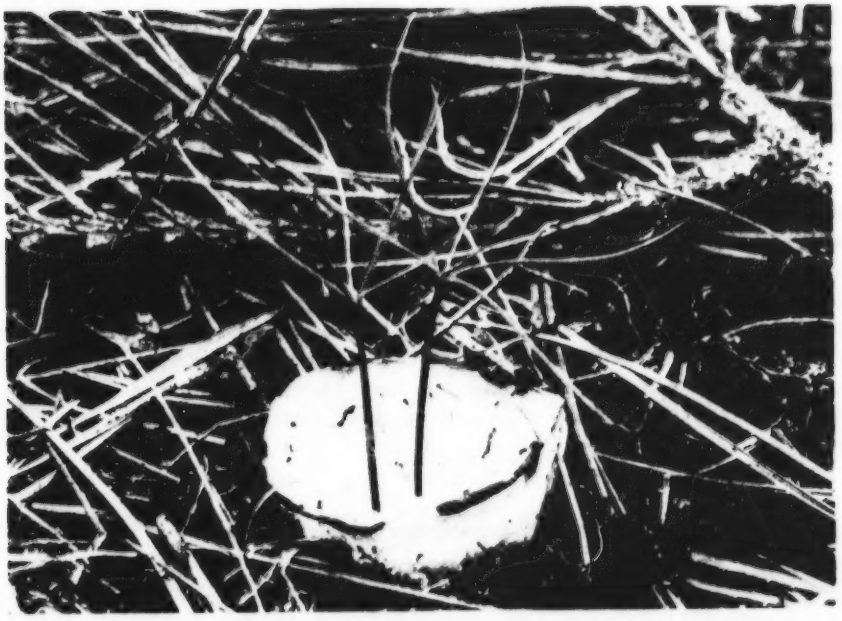

Figure 5. Open dart with young jack pine germinants.

Figure 6. Open dart with older jack pine seedlings.

The drying curves for the commercial growing media (Fig. 7) were essentially the same, reaching their minimum moisture content after 5 days of passive drying (Appendix III). The only exception was composted pine bark (Ball Growing Mix I) which, because of a low initial moisture content, had a significantly lower regression (Table 2). However, the slope of the drying curve for this material did not differ significantly from that of the other commercial mixtures and it also reached a minimum moisture content by the fifth day.

Of the locally blended mixtures (Fig. 8), peat:vermiculite (#2) performed much the same as the commercial peat-lite growing media, with a drying curve practically identical to that of Pro-Mix A. However, the addition of Turface® to the former caused a significant lowering of the regression (Table 2). This may be attributed to a lower water holding capacity at the beginning of the test, probably as a result of dilution of the water-absorbing components of the medium. It will be noted that the peat:vermiculite:Turface® mixture dried to the 10% moisture level approximately one day earlier than the material without ballast, and that its residual moisture content was also the lowest of all media at the end of the test.

Table 2. Comparison of drying curve regressions.[a]

Regressions compared[b]	Slope[c]	Level[d]
P vs P:V	1.21	5.91*
P vs P:V:Turface®	0.44	0.91
P:V vs P:V:Turface®	0.44	21.11**
P:V vs P:V:Aqua-Terra ®	2.68	12.50**
P:V: vs P:V:"Super-Slurper"	0.73	7.18*
P:V:Aqua-Terra® vs P:V:"Super-Slurper"	0.48	1.09
P:V vs Forestry Mix	0.01	1.22
Forestry Mix vs Ball Growing Mix I	1.70	5.85*
Forestry Mix vs Pro-Mix A	0.37	1.51
Ball Growing Mix I vs Pro-Mix A	0.94	3.29

[a]Based on linear regressions fitted to transformed (square root) data.

[b]P = peat moss; V = vermiculite

[c]10 degrees of freedom } * = significant at 5% level
[d]10 degrees of freedom } ** = significant at 1% level

The drying curve for pure peat moss (#1) is one of the least desirable, and demonstrates the ease with which readily available water may be lost from this material through evaporation or easy exploitation by plants *(vide* Beardsell et al. 1979). Despite a reasonably high water holding capacity at "field capacity", the moisture content was reduced from 76% to 30% after only two days of drying, approximately two days before peat:vermiculite (#2) and most commercial media reached the same level.

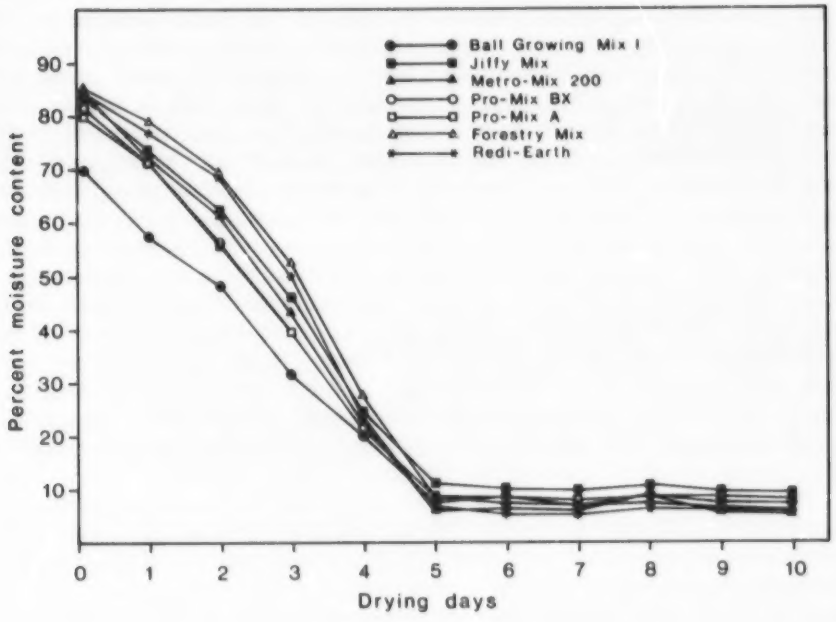

Figure 7. Rates of moisture loss from commercial growing media.

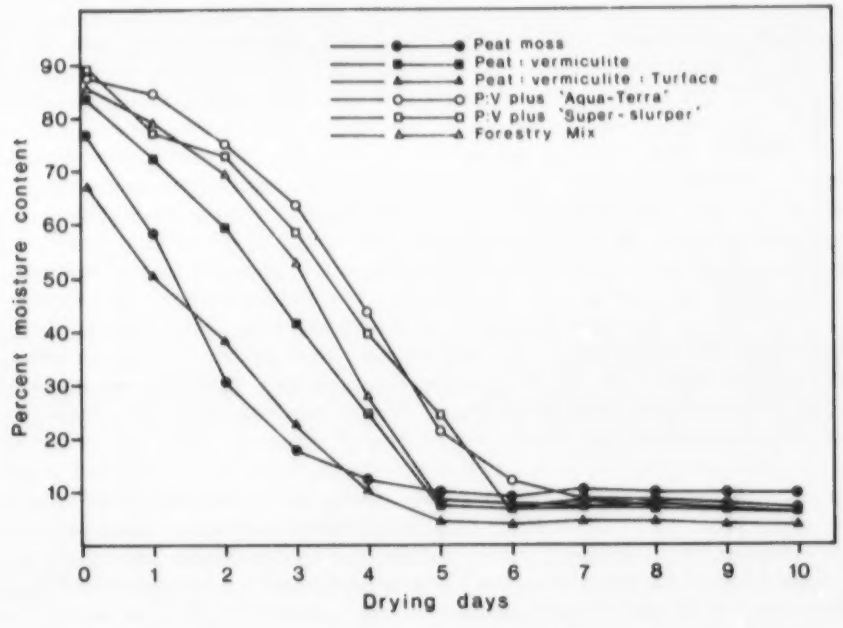

Figure 8. Rates of moisture loss from locally blended growing media, and effect of amendment with hydrophyllic polymers.

The addition of hydrophilic polymer at the recommended rates did not result in any great increase in the water-holding capacity of peat:vermiculite (Table 1). However, both Aqua-Terra® and "Super-Slurper" did bring about a significant improvement in moisture retention during drying. Figure 8 reveals that, between the third and sixth days especially, there was approximately a one-day lag in moisture loss in comparison with media that had no polymer additive. Whereas all other media reached equilibrium moisture content at five days, "Super-Slurper" and Aqua-Terra® did not reach this point until the sixth and seventh days, respectively. Although it is difficult to judge the biological significance of such a lag in terms of application to the aerial dart, any reduction in moisture loss must be viewed as potentially beneficial in helping seedlings to survive a drought period, provided that the residual moisture remains available for seedling use. It should be emphasized, though, that the amounts of polymer used here were those recommended for horticultural crops, which are not normally subjected to long periods of high soil moisture tension. Higher rates may be necessary to cope with the severe drought conditions likely to be encountered on forest sites, although the need for a physically stable growing medium may impose limits on the amount of additive used.

This comparison of moisture retention in different growing media was based solely upon the measurement of residual moisture content as drying progressed. In practice, of course, the moisture content of a growing medium is not necessarily indicative of the availability of that moisture for plant use. Nor, as pointed out by Beardsell et al. (1979), is there necessarily a direct relationship between the water holding capacity of a medium and its ability to retain available water at high moisture tensions - an essential characteristic for aerial darts. Consequently, the results reported here cannot be used directly to judge the suitability, for darts, of one material over another. Clearly, more detailed studies of the moisture relations of soilless mixtures are needed before selections can be made for this particular application.

Nevertheless, the results of this simple drying test do provide a few pointers. By and large, there appears to be little to choose between different peat-lite mixtures in terms of moisture retention. Rates of drying will be influenced to some extent by the particle size and degree of decomposition of the peat component in the mix although, as noted earlier, the available water in peat moss is generally held at low tensions and tends to be easily lost. On the other hand, the literature indicates that bark-based growing media may be better able to retain available water at high moisture tensions, and may therefore be superior to peat mixtures where they are prone to drying. For this reason, they obviously warrant further testing. While not a major selection factor, the higher bulk density of bark media may be a secondary benefit in view of the probable need to increase dart weight and the undesirability of adding ballast to soilless mixtures.

Although no large increase in moisture retention resulted from the use of hydrophilic additives in this trial, it certainly appears worthwhile to pursue further experimentation. Several other polymers besides those used here are now available commercially (Appendix II). Each would need to be extensively tested in order to select the most appropriate material and to optimize rates for use in aerial darts.

While there is reason to be optimistic that use of hydrophilic polymers can improve moisture retention in aerial darts, numerous questions remain. For example, most of the beneficial results reported for horticultural crops were based upon experience at moderate moisture tensions. However, it is not clear whether polymers are able to increase materially the retention of *available* water at high moisture tensions. Yet this is where the critical need lies if dart seedlings are to be assisted in surviving typical drought conditions. Despite manufacturers' claims that 90% or more of the water held by polymers is available for plant use, this will be of little benefit if most of that water is lost at low to moderate tensions. A related question is how much polymer must be added to achieve significant improvements in seedling survival. If, as suggested earlier, it is found necessary to employ higher rates than those recommended for horticultural crops, there may well be objections to the use of some products because they cause excessive expansion of amended growing media when these are wetted. Even at the rates used in this trial, both Aqua-Terra® and "Super-Slurper" swelled sufficiently when wetted to cause minor overflowing of the containers. We must also be sure that, by increasing the amount of polymer additive, we do not risk inhibiting germination or seedling growth, or even increase water loss from seedlings through reverse osmosis during periods of drought. Although horticultural experience (e.g., Gehring and Lewis 1980) has generally shown no adverse effects of high amendment rates, the results may be quite different under the more severe conditions to which aerial darts will be exposed. These, then, are some of the questions that must be addressed in evaluating hydrophilic polymers for this particular application.

CONCLUSIONS

Although major progress has been made in developing an airborne delivery system to support the aerial dart concept, critical biological problems remain. Aside from concerns relating to the distribution and penetration of darts on the forest floor, the vulnerability of darts to drought clearly poses a serious obstacle to their potential operational effectiveness. Unless problems of moisture supply and moisture retention within the dart can be resolved, it is unlikely that the technique can reliably achieve biological success on typical cutover conditions in the boreal forest.

For the aerial dart to have any chance of succeeding as a viable regeneration method, it is imperative that a growing medium be found which is capable of promoting germination and supporting seedling development under the rather severe moisture conditions that can exist on cutover sites. There are two specific requirements that must be satisfied as long as a seedling remains dependent upon the growing medium in the dart. First, the medium must be able to absorb and store sufficient moisture to promote rapid germination and enable the germinant radicle to become firmly established. Second, the medium must retain sufficient available water at high moisture tensions to permit young seedlings to survive brief periods of surface desiccation.

Available evidence indicates that most soilless media on the market today are unable to satisfy the stringent moisture requirements for satisfactory performance of aerial darts. Although such media may hold large amounts of water at saturation, their ability to retain moisture under drought conditions is

generally inadequate for this special application. The problem is exacerbated by the small capacity of the aerial dart, which severely restricts the moisture reservoir that can be stored by the contained growing medium.

Despite these drawbacks, the best opportunity for developing a suitable growing medium probably rests with the modification of traditional soilless media. Through choice of ingredients, with careful attention to their physical condition and degree of humification (in the case of organic components), it may be possible to achieve some improvement in the moisture characteristics of such media. Composted bark products, especially, appear to warrant more detailed examination, mainly because of their particular moisture relations, but also because their high bulk density may be advantageous in aerial dart design. However, manipulation of physical condition alone is not likely to bring about the substantial improvement in moisture retention that is necessary for successful use of aerial darts. Perhaps the most promising means of achieving this goal is through the amendment of soilless growing media with hydrophilic polymers, some of which are able to absorb many times their own weight of water. Although extensive testing will be required to evaluate potential benefits, several of the polymers now available for horticultural use appear to hold considerable promise for ameliorating the sensitivity of darts to drought.

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APPENDICES

APPENDIX I

COMPOSITION OF SOME COMMERCIAL GROWING MEDIA AVAILABLE IN CANADA[1]

Growing medium	Composition[2]
Ball Growing Mix I	Composted pine bark, vermiculite and perlite, with liquid starter nutrient solution, limestone and wetting agent. Coarse texture.
Ball Growing Mix II	Same ingredients as Ball Growing Mix I, but finer texture, with the addition of *Sphagnum* peat moss.
Grace Redi-Earth®	Equal parts *Sphagnum* peat moss and #3 fine grade vermiculite, with addition of basic Cornell peat-lite nutrient charge and wetting agent.
Grace Metro-Mix® 200	Similar to Redi-Earth® but with addition of horticultural perlite and washed granite sand.
Grace Metro-Mix® 220	Similar to Redi-Earth® but with addition of horticultural perlite only (no granite sand). Coarser than Metro-Mix® 200.
Grace Metro-Mix® 240	Coarse blend of block-cut *Sphagnum* peat moss, #2 medium grade vermiculite and horticultural perlite, with addition of basic Cornell peat-lite nutrient charge and wetting agent.
Grace Metro-Mix® 245	Same ingredients as Metro-Mix® 240, but in different proportions and of coarser texture (*Sphagnum* peat moss 60%; vermiculite 30%; perlite 10%). Contains basic Cornell peat-lite nutrient charge and wetting agent.
Grace Forestry Mix	*Sphagnum* peat moss and horticultural grade vermiculite plus starter fertilizer charge and wetting agent. The pH is adjusted within the range 4.0-5.0 specifically for growing conifer seedlings.
Lambert Vita Mix	*Sphagnum* peat moss (60%), vermiculite (20%), and coarse grade perlite (20%), with addition of basic Cornell peat-lite nutrient charge, trace elements and wetting agent (Aqua-Gro).

(continued)

APPENDIX I

COMPOSITION OF SOME COMMERCIAL GROWING MEDIA AVAILABLE IN CANADA[1] (cont'd)

Growing medium	Composition[2]
Jiffy Mix	Equal parts *Sphagnum* peat moss and #3 fine grade vermiculite, plus starter fertilizer.
Premier Pro-Mix A	*Sphagnum* peat moss (60%) and vermiculite (40%) with addition of basic Cornell peat-lite nutrient charge, fritted trace elements and granular wetting agent.
Premier Pro-Mix BX	*Sphagnum* peat moss (60%), vermiculite (20%) and perlite (20%), with same nutrients as Pro-Mix A plus granular wetting agent. Somewhat coarser than Pro-Mix A.
Shamrock Speedel® Regular	*Sphagnum* peat moss (65%), vermiculite (22%), perlite (5%), composted fir bark (5%) and red-fired clay particles (3%), with nutrient charge (dolomitic limestone, superphosphate, calcium nitrate and ferrous sulphate), trace elements and wetting agent. pH 6.2
Shamrock Speedel® 200X	*Sphagnum* peat moss (65%) and vermiculite (35%) with same nutrient charge as regular mix, trace elements, wetting agent, and fungicides (Benlate® and Redomil®). pH 6.2
Shamrock Forestry Mix	*Sphagnum* peat moss (72%), #3 fine grade vermiculite (24%) and washed sand (4%), with wetting agent. Optional major nutrient and trace element charge. pH 5.0
Sunshine® Mix Blend 1	*Sphagnum* peat moss (80%), vermiculite and perlite (20% total) with dolomitic limestone and nutrient charge (potassium nitrate, calcium nitrate and superphosphate), trace elements and wetting agent. pH 5.0-5.5 as packaged, rising to pH 5.6-6.2 after watering.
Sunshine® Mix Blend 2	Same as Sunshine® Mix Blend 1, but contains no added nutrients or trace elements. Contains dolomitic limestone and wetting agent.

(continued)

APPENDIX I

COMPOSITION OF SOME COMMERCIAL GROWING MEDIA

AVAILABLE IN CANADA[1] (concl'd)

Growing medium	Composition[2]
Sunshine® Mix Blend 3	A fine-textured mix formulated for seed germination and plug culture. Contains *Sphagnum* peat moss (80%) and vermiculite (20%), with dolomitic limestone, starter fertilizer (includes all major nutrients and trace elements), and wetting agent.

[1] This is not an exhaustive list of available growing media. An increasing number of companies are beginning to produce peat-lite mixtures for horticultural use; some will custom-blend growing media.

[2] Information derived mostly from trade literature; ingredient porportions are not always freely available.

Notes: Most growing media, with the exception of the Grace and Shamrock Forestry Mixes, have a pH in the range 5.5-6.5.

The fertilizer charge incorporated into many soilless mixes is intended only as a starter and is readily leached. In horticultural practice liquid nutrients would normally be used for long-term feeding.

APPENDIX II

SOME ABSORBENT ADDITIVES FOR INCREASING MOISTURE RETENTION

IN SOILLESS GROWING MEDIA

Trade name	Manufacturer (M) or supplier (S)	Active ingredient and characteristics[1,2]
Agrosoke®	(M) Chemical Discoveries (UK) Ltd. Mamhilad Park Estate Pontypool, Gwent South Wales, U.K. NP4 0D2 (represented in Canada by: Rogers Bros. Ltd. P.O. Box 2061 Saint John, N.B.)	Ingredient not identified, but reported as polyacrylinid polymers (crystalline; absorbs 30 times its own weight of water; expands on wetting)
Aqualon®	(M) Hercules Inc. 910 Market Inc. Wilmington, Del. 19899	Internally cross-linked sodium carboxymethylcellulose (CMC) fibre (fibrous; absorbs up to 45 times its own weight of water; no major volume increase on wetting)
Aqua-Lox	(M) Southern Hydro Mulch Supply, Inc. P.O. Box 59413 Dallas, Texas 75229	Hydrolyzed starch-polyacrylonitrile graft copolymer (fine powder; absorbs 400+ times its own weight of water; substantial expansion on wetting)
Aqua-Terra® (also sold as Water-Power®)	(M) CC Chemicals Ltd. 89 Langstaff Road East P.O. Box 860 Thornhill, Ontario L3T 4A5	Hydrolyzed starch-polyacrylonitrile graft copolymer blended into an inert extender (crystalline; in pure form absorbs 200-400 times its own weight of water; expands on wetting)
Liqua-Gel® (formerly Aqua-Gel)	(M) Miller Chemical and Fertilizer Corp. P.O. Box 333 Radio Road Hanover, Pennsylvania 17331	Hydrolyzed starch-polyacrylonitrile graft copolymer (fine powder; absorbs 600-800 times its own weight of water; substantial expansion on wetting)

(continued)

APPENDIX II

SOME ABSORBENT ADDITIVES FOR INCREASING MOISTURE RETENTION

IN SOILLESS GROWING MEDIA (concl'd)

Trade name	Manufacturer (M) or supplier (S)	Active ingredient and characteristics[1,2]
"Super-Slurper" (SGP® 502S)	(M) Henkel Corporation General Mills Division 4620 West 77th Street Minneapolis, Minn. 55435	Hydrolyzed starch-polyacrylonitrile graft copolymer (fine powder; absorbs several hundred times [up to 2000 times reported] its own weight of water; substantial expansion on wetting)
Terra-Sorb®	(M) Industrial Services International, Inc. P.O. Box 10834 Bradenton, Fla. 33509	Hydrolyzed starch-polyacrylonitrile graft copolymer (granular; absorbs several hundred times its own weight of water; 30% volume increase on wetting; 95% moisture availability)
	(S) Albion Seed P.O. Box 492 Bolton, Ontario L0T 1A0	
Viterra® Planta-Gel (formerly Agric-cultural Hydrogel, manufactured by Union Carbide cultural Systems)	(M) Nepera Chemical Company, Inc. Route 17 Harriman, New York 10926	Potassium propenoate-propenamide copolymers (crystalline; absorbs 200-400 times its own weight of water or 150 times its own weight of solution containing 220 ppm of Peters® 20-20-20 fertilizer)
	(S) Harry Sharp and Sons Ltd. 1155 Appleby Line, Unit E5 Burlington, Ontario L7L 5H9	

[1] Information derived from trade literature.

[2] Absorbencies refer to uptake of deionized water by the pure product.

APPENDIX III

PROCEDURE FOR COMPARING DRYING RATES OF GROWING MEDIA

In order to simplify this comparison no attempt was made to use or to simulate the aerial dart. Rather, since the objective was to determine the drying rates of small volumes of growing medium, Japanese paperpots were used to hold the medium. Sets of FH 308 paperpots were cut to half-depth to produce a container with an approximate diameter of 3.0 cm, depth of 3.7 cm, and volume of 22 cm^3. Although the volume of the container was approximately twice that of the aerial dart, the paperpot was selected for its ease of handling and because it allowed moisture movement through the container wall, as does the dart.

Twelve growing media were included in the drying test, seven of them commercial products, *viz:*

A. Locally Blended Mixtures

1. Fafard brand *Sphagnum* peat moss, shredded and screened (8 mesh).
2. 1:1 mixture of Fafard peat moss, as above, and horticultural grade (#2) vermiculite.
3. 1:1:1 mixture of Fafard peat moss, horticultural grade vermiculite and regular grade sintered clay aggregate (Turface®).
4. 1:1 peat/vermiculite mixture, as in 2, with addition of 3.50 kg/m^3 (pure ingredient) Aqua-Terra® hydrophilic polymer.
5. 1:1 peat/vermiculite mixture, as in 2, with addition of 2.05 kg/m^3 "Super Slurper" hydrophilic polymer.

B. Commercial Mixtures

6. Jiffy mix
7. Grace Redi-Earth ®
8. Grace Metro-Mix ®200
9. Grace Forestry Mix
10. Ball Growing Mix I
11. Premier Pro-Mix A
12. Premier Pro-Mix BX

None of the locally blended mixtures contained fertilizers or wetting agents; Turface® was incorporated into mixture 3 to determine the effect of adding ballast to a growing medium.

Separate sets of half-depth paperpots (532 pots per set) were filled with each of the 12 growing media on a vibratory loading table. After filling, the pots were watered to saturation over a 48-hour period; warm water was used to ensure thorough wetting of the non-commercial media. The trays were then covered with plastic sheets and allowed to drain for a further 24 hours on shaded greenhouse benches (20°C). At the end of this period, 20 pots of each medium were sampled to determine their water holding capacities.

For the drying test, individual pots were removed from the paperpot sets, care being taken not to disturb the growing medium, and were placed upright at 8 cm spacing in solid-bottomed plastic trays. Each tray accommodated eight randomly assigned pots of growing medium. The trays were then filled quickly with oven-dried mortar sand so as to engulf the individual containers to the full depth of the pot wall. After filling, the trays were transferred to well aerated racks in a growth chamber (20°C, 30% RH), where the media were allowed to dry passively. Over the next 10 days four pots of each medium were removed every 24 hours and were cleaned of sand, and the medium was removed for moisture content determination (48 hours at 70°C).